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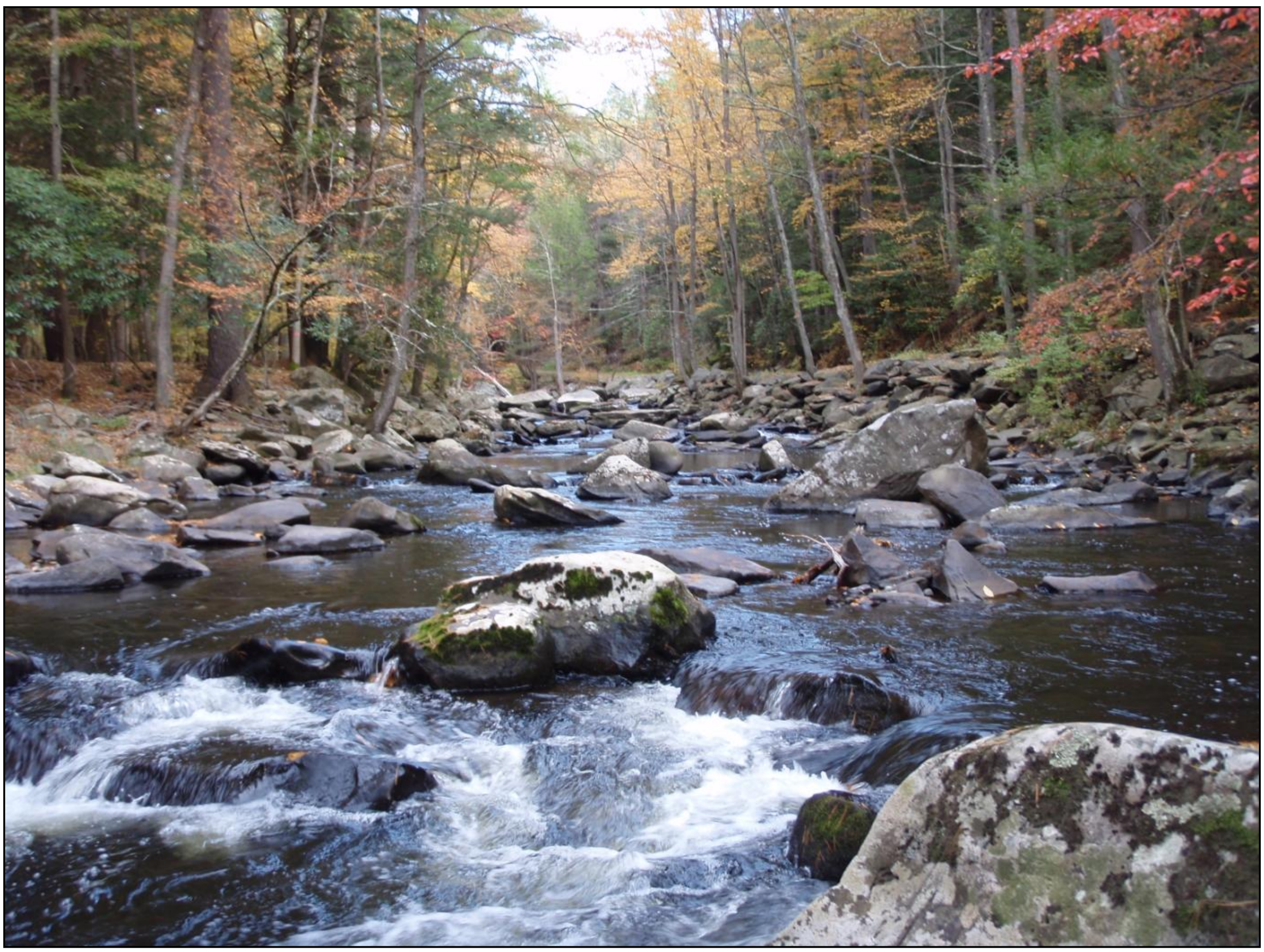
Integrity of benthic macroinvertebrate communities in the Upper Delaware Scenic and Recreational River

Eastern Rivers and Mountains Network 2008 summary report

Natural Resource Data Series NPS/ERMN/NRDS—2010/029



ON THE COVER
Ten Mile River in Upper Delaware Scenic and Recreational River
Photograph by: Caleb Tzilkowski.

Integrity of benthic macroinvertebrate communities in the Upper Delaware Scenic and Recreational River

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All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner. Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols.

This report is available from the Eastern Rivers and Mountains Network website (http://science.nature.nps.gov/im/units/ERMN) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/NRPM).

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Abstract

During 2008, the Eastern Rivers and Mountains Network (ERMN) of the National Park Service (NPS) began monitoring benthic macroinvertebrate (BMI) communities in wadeable streams throughout its nine parks. There were 12 targeted (non-random) sites sampled throughout Upper Delaware Scenic and Recreational River (UPDE) during October 2008. Sampled streams were selected based primarily on their high dilution ratios (i.e., relative contribution of water to the Delaware River), whereas site locations on those streams were selected based upon landowner cooperation. In addition to BMI samples, core water quality data (i.e., temperature, dissolved oxygen, pH, and specific conductance) were collected and reach-scale habitat was characterized.

Core water quality parameters at UPDE sites were typical of forested watersheds with similar geologic characteristics. Relationships among core parameters were also typical – specific conductance generally decreased with decreasing pH, whereas dissolved oxygen concentrations (DO) consistently decreased with increasing water temperature. There were no exceptionally warm or cold streams throughout UPDE given the fall sampling period, and DO concentrations were typically at or above saturation levels. Benthic macroinvertebrate communities throughout UPDE streams had Macroinvertebrate Biotic Integrity Index values that ranged from 46.9 (West Branch Delaware River) to 65.8 (Equinunk Creek).

Given that this report represented the first year of data collection, there were few inferences or management recommendations that could be confidently made. Biological communities (including BMI) can vary through time due to a range of naturally occurring biotic phenomena (e.g., interspecific competition, predation) and abiotic disturbances (severe drought, floods). It will take several years to determine the degree to which BMI communities naturally vary throughout UPDE and the rest of the ERMN. Once natural variability of BMI communities is quantified, we will be in a better position to make inferences about the relative condition of sampled streams.

Introduction

During 2008, the Eastern Rivers and Mountains Network (ERMN) of the National Park Service (NPS) began monitoring benthic macroinvertebrate (BMI) communities in wadeable streams throughout its nine parks. This monitoring effort is a component of the ERMN Vital Signs monitoring program (Marshall and Piekielek 2007) as part of the nationwide NPS Inventory and Monitoring Program (Fancy et al. 2009).

One of the primary objectives of the ecological monitoring program in the ERMN is to evaluate status and trends in the condition of tributary watersheds flowing into and through member parks. Watershed condition is evaluated using measures of ecosystem integrity, including streamside bird species and communities (Mattsson and Marshall 2009), forest structure and composition (Perles et al. 2009), stream-dwelling benthic macroinvertebrates (Tzilkowski et al. 2009), stream chemistry, and watershed land use, type, and configuration (Marshall and Piekielek 2007). A primary purpose of the benthic macroinvertebrate monitoring protocol is to support the antidegradation or restoration of ERMN aquatic communities and their habitat (including water quality) by communicating monitoring program results to appropriate regulatory state and federal agencies.

Benthic macroinvertebrates are aquatic invertebrate animals larger than microscopic size that live on or within the stream bottom (benthos), and because they are a vital component of all functioning stream ecosystems, they are often used as indicators of ecosystem integrity. Types of BMI that are commonly used for water quality assessment include arthropods (insects, arachnids, and crustaceans), worms, clams, and snails. In addition to being instrumental to nutrient and carbon dynamics, BMI are an important link between basal resources (e.g., algae and detritus) and higher trophic levels (e.g., fish and birds) in stream food webs. Because BMI have been by far the most commonly used group for biological monitoring of aquatic ecosystems (Carter and Resh 2001) many metrics have been evaluated with respect to natural variation and responses to various sources of human-induced degradation. Given the proven ability to derive ecosystem integrity based on measures of BMI assemblage structure and composition, combined with the relatively low cost to sample, BMI are almost certainly the single best biological group to assess and monitor the ecological integrity of small and mid-sized streams.

At the time that this report was prepared, the BMI monitoring protocol (Tzilkowski et al. 2009) had been developed, written, and received internal peer review but had not undergone the final peer review process. This report was intended to provide preliminary results to natural resource managers at Upper Delaware Scenic and Recreational River (UPDE) and at cooperating entities (e.g., Delaware River Basin Commission). The preliminary nature of data presented in this report should be considered prior to its use or dissemination.

Methods

Although a brief overview of the BMI monitoring methods is provided here, a detailed rationale of the sampling design and methods, in addition to Standard Operating Procedures, are provided in the BMI Monitoring Protocol (Tzilkowski et al. 2009). Much of the protocol is based on protocols developed by the U.S. Geological Survey ([USGS] Moulton et al. 2000, Moulton et al. 2002) and Bowles et al. (2006) because those methods have undergone considerable evaluation and revision. We modified those protocols to fit the character of ERMN parks and anticipated monitoring resources.

Site Selection

There are two types of sampling sites in the BMI Monitoring Program – probabilistic (i.e., stratified-random) sites and non-random "targeted" sites. The probability-based design was developed by Mattsson and Marshall (2009) for the ERMN Streamside Bird Monitoring Program but was not used at UPDE due to the linear nature of the park and lack of federal land ownership. Instead, 12 targeted sites were chosen on 12 different streams in consultation with UPDE natural resource managers (Don Hamilton and Jamie Myers; Figure 1). Those streams were chosen based primarily on their high dilution ratios (i.e., relative contribution of water to the Delaware River) and their inclusion in the Scenic Rivers Monitoring Program. Site locations on those streams were selected based in large part upon landowner cooperation which was coordinated largely by UPDE staff.

Field Methods

The sampling unit for the BMI monitoring program is the stream reach, which for the ERMN program is defined as a length of stream chosen to represent a uniform set of physical, chemical, and biological conditions within a stream segment. The length of sampled reaches differs among watersheds but their length is proportional (i.e., 40 ×) to stream width. Minimum and maximum reach lengths are 150 m and 500 m, respectively. Tributary reaches within floodplains of large rivers (e.g., Delaware River) were typically not considered for sampling because those sites are thought to exhibit considerable natural variation.

Sampling was conducted during October 2008. The ERMN method for collecting BMI throughout UPDE is termed semi-quantitative richest-targeted habitat (RTH, Moulton et al. 2002) sampling which is a type of disturbance-removal sampling. Although similar to more common kick sampling methods, RTH sampling calls for consistent and thorough collection of BMI from a fixed area; thus, it is considered a more precise method and allows for estimation of stream productivity unlike many other sampling methods. Many BMI disturbance-sampling methods are qualitative (not quantitative) and are comparatively inconsistent because there is no measurement of sampling area—instead, those methods usually rely on a timed sampling effort. For the RTH method, five discrete samples are collected from riffles throughout the reach and are ultimately composited into a single homogenous sample. Ideally, discrete samples are taken from different riffles, but if fewer than five riffles are present, samples may be taken from the same riffle. Physical conditions (i.e., depth, flow, and substrate) are recorded at each sampling location and should be as similar as possible among replicates. Sampling is conducted by defining a 0.25 m^2 sampling area with a template and then disturbing substrate within that area so that BMI are dislodged and then drift into a net placed downstream of the sampling area. The composited samples result in 1.25 m^2 of sampled area at each site.

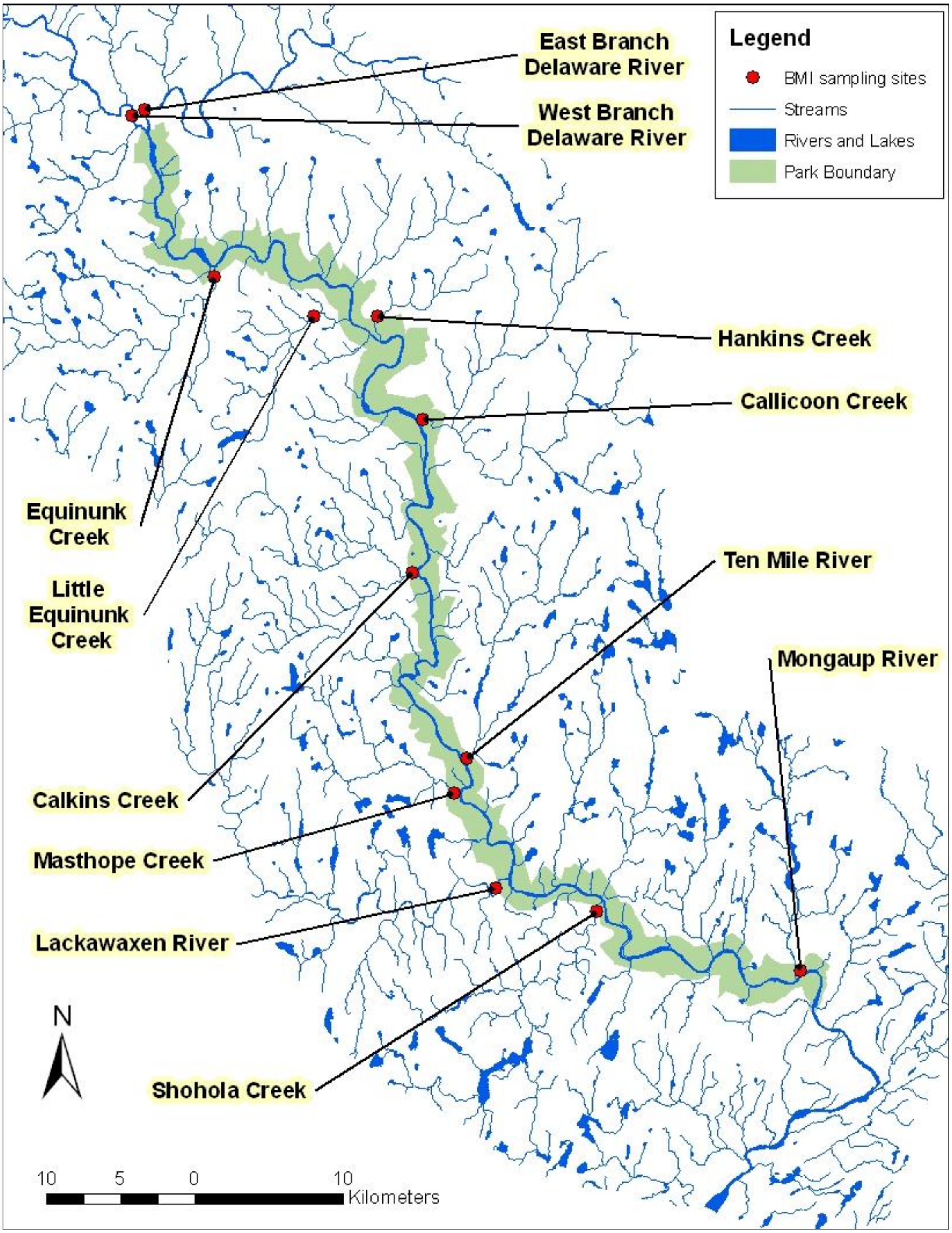

Figure 1. Benthic macroinvertebrate sampling sites throughout Upper Delaware Scenic and Recreational River.

In addition to BMI samples, core water quality data (i.e., temperature, dissolved oxygen, pH, and conductivity) are collected and reach-scale habitat is characterized using the U.S. Environmental Protection Agency (USEPA) rapid bioassessment method (Barbour et al. 1999). Samples are processed in the field by using an elutriation method to remove mineral materials and large organic matter (e.g., whole leaves and sticks). Samples are preserved in 95% ethanol, packed carefully, and transported back to the laboratory for processing and identification.

Laboratory Methods

Laboratory methods for processing samples in the ERMN BMI Program rely a great deal on procedures developed by the USGS (Moulton et al. 2000). A fixed-count subsample of 300 ± 20% individuals are sorted and identified from each sample. The relatively large subsample size yields data that meets quality standards (i.e., precision and accuracy) required by most monitoring programs; however, processing and identifying additional individuals (>300) does not typically yield enough additional information to justify the added effort (Moulton et al. 2000). Generally, BMI were identified to genus using standard dichotomous keys, but some groups (e.g., Chironomidae, Oligochaeta) were identified to coarser taxonomic levels. Microsoft Access 2007 is the primary software used for storing and managing ERMN BMI and stream habitat data, whereas the Invertebrate Data Analysis System (IDAS *version 5*, U.S. Geological Survey, Raleigh, NC) was used for resolving taxonomic ambiguity issues and calculating metrics that describe the structure and diversity of BMI communities.

Data Analysis

We calculated all available BMI community metrics possible with IDAS and then calculated the Macroinvertebrate Biotic Integrity Index ([MBII] Klemm et al. 2003) using Microsoft Excel 2007. The MBII was developed by the USEPA Environmental Monitoring and Assessment Program (EMAP) and was ultimately used for the USEPA's Wadeable Stream Assessment (WSA, USEPA 2006, Herlihy et al. 2008).

The rationale behind biotic integrity indices is that a suite of metrics that represent community structure, pollution tolerance, functional feeding groups and habitat occurrences, life history strategies, disease, and density provide insights regarding how biological communities respond to different natural and anthropogenic stressors (Klemm et al. 2003). A common stream bioassessment practice is to compare BMI community metrics from candidate streams to the same metrics from reference streams. Reference streams are "least disturbed," similarly sized streams within comparable geographic and geologic settings that provide an estimate of least-impaired stream communities. Departure of the sampled BMI community from expected BMI community composition (i.e., reference streams) serves as a measure of stream impairment. The MBII is one such index that uses reference streams to assess stream impairment.

The MBII was chosen for use in the ERMN because it was developed for upland and lowland streams dominated by riffle habitat in the Mid-Atlantic Highlands Region (MAHR). Moreover, the MBII was based on a large dataset of 574 wadeable stream reaches and was thoroughly tested. The MBII is a broadly applicable measure of stream impairment because it is based on several factors that affect aquatic communities throughout the MAHR. Impaired and reference streams for the MBII were identified by Klemm et al. (2003) using water chemistry, qualitative habitat, and minimum organism count criteria. Impaired reaches were defined by meeting any one of the following criteria: pH <5, chloride >1000 µeq/L, sulfate >1000 µg/L, total phosphorous >100 µg/L, total nitrogen >5000 µg/L, or a mean qualitative habitat score <10 (of a possible 20). Reference reaches met all of the following criteria (Klemm et al. 2003): sulfate <400 µg/L, Acid Neutralizing Capacity (ANC) >50 µeq/L, chloride <100 µeq/L, total phosphorous <20 µg/L, total nitrogen <750 µg/L, mean qualitative habitat score >15, and at least 150 organisms.

The MBII uses seven metrics selected from the 100 that are commonly used by governmental agencies throughout the MAHR. The metrics chosen were those that performed best in terms of range, precision, responsiveness to various human-induced disturbances, relationship to catchment area, and redundancy (Table 1; Klemm et al. 2003). Most MBII metrics are counts or proportions of taxa in the community that are characterized as tolerant or intolerant to human perturbations; however, one of the metrics (Macroinvertebrate Tolerance Index; MTI) is more complex because it incorporates values (0–10) for each taxon with respect to pollution tolerance, weighted by taxon abundance, and results in higher scores as the proportion of taxa tolerant to general pollution increases (Klemm et al. 2003). Pollution Tolerance Values (PTV) incorporated in the MTI were average tolerances to “various types of stressors” (Klemm et al. 2002).

Table 1. Macroinvertebrate Biotic Integrity Index metric descriptions and their directions of response to increasing human perturbation (Response) from Klemm et al. (2003).

Metric	Description	Response
Ephemeroptera richness	Number of Ephemeroptera (mayfly) taxa	Decrease
Plecoptera richness	Number of Plecoptera (stonefly) taxa	Decrease
Trichoptera richness	Number of Trichoptera (caddisfly) taxa	Decrease
Collector-filterer richness	Number of taxa with a collecting or filtering-feeding strategy	Decrease
Percent non-insect individuals	Percent of individuals that are not insects	Increase
Macroinvertebrate Tolerance Index	$\sum_i p_i t_i$, where p_i is the proportion of individuals in taxon i and t_i is the pollution tolerance value (PTV) for general pollution	Increase
Percent five dominant taxa	Percentage of individuals in the five numerically dominant taxa	Increase

We also present three other commonly used BMI community metrics (taxa richness, Shannon’s Diversity and Evenness) for comparison because they are likely to be familiar to most readers of this report. Taxa richness was the combined number of unique taxa (usually genera). Shannon’s diversity and evenness were calculated with IDAS using formulae provided by Brower and Zar (1984), which were:

Shannon’s Diversity (H`): information theory-based index that measures the “uncertainty” of a taxon selected at random from the community. High diversity is associated with high uncertainty and low diversity with low uncertainty. This index is the equivalent of the Brillouin’s diversity index, but it is intended for use when the abundance data come from a random sample of the community or subcommunity.

$$H` = (N \log_{10} N - \Sigma\, n \log_{10} n)/N$$

Shannon's Evenness (J`): ratio of the observed Shannon diversity to the maximum possible diversity (that is, diversity when individuals are distributed as evenly as possible among the species). Like the Shannon diversity index, this measure is intended to be used when the abundance data come from a random sample or the community or subcommunity

$$J` = H`/H_{max}` \text{ where } H_{max}` = \log_{10} S$$

Abbreviations used in formulae: S = number of taxa in sample, n = abundance of an individual taxon, N = total number of individuals in sample.

Results

Benthic Macroinvertebrate Communities

Benthic macroinvertebrate communities throughout UPDE streams had MBII values that ranged from 46.9 (West Branch Delaware River) to 65.8 (Equinunk Creek; Figure 2). Based on MBII thresholds for the Northern Appalachians Ecoregion (Herlihy et al. 2008), there were two UPDE streams (Equinunk Creek, Ten Mile River) that were considered to be in the "Good" condition class. There was only one stream (West Branch Delaware River) in the "Poor" condition class, whereas the remaining nine streams sampled were considered to be in "Fair" condition.

Total taxa richness among UPDE streams ranged from 23 (West Branch Delaware River) to 35 (Equinunk Creek; Table 2). Among richness metrics, collector or filterer richness was most consistent among streams and ranged only from five to seven taxa. Although Mongaup River ranked sixth in terms of overall MBII score, there were 28 combined Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa in that sample, which was more than any other stream. No other stream had more than 23 EPT taxa – the West Branch Delaware River sample had the fewest EPT taxa (15). The proportional metrics (% Non-insects and %5 dominant) and Shannon diversity and evenness metrics generally responded as expected – with increasing MBII scores, the proportional and Shannon metrics decreased and increased, respectively. Finally, as anticipated, the MTI decreased with increasing MBII scores and ranged from 3.8–4.9. Density of BMI was considerably different among UPDE streams and ranged from 1,833 m^{-2} (Masthope Creek) to 9,377 m^{-2} (Callicoon Creek; Figure 3).

Water Quality

Physical and chemical characteristics can vary markedly, both daily and annually. Although there are limitations to point-in-time characterizations of core water quality parameters, these measures can be helpful when evaluating patterns in biological data; moreover, extreme changes to these parameters can sometimes be detected with point-in-time samples. Core water quality parameters (pH, specific conductance, temperature, DO) at UPDE sites were typical of primarily forested watersheds with similar geologic characteristics. Relationships among core parameters were also typical – specific conductance generally increased with increasing pH (Figure 4), whereas DO concentrations consistently decreased with increasing water temperature (Figure 5).

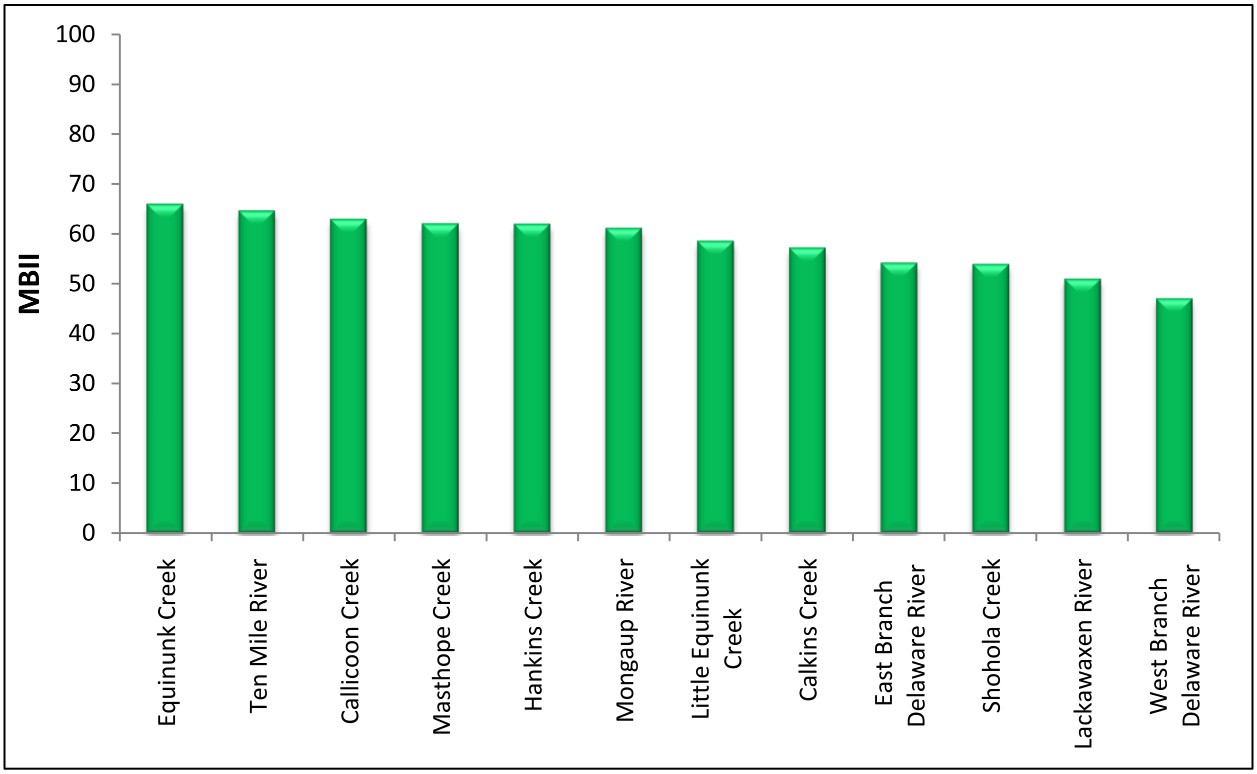

Figure 2. Macroinvertebrate Biotic Integrity Index (MBII, Klemm et al. 2003) values for benthic macroinvertebrate samples collected at sampling sites throughout Upper Delaware Scenic and Recreational River in October 2008.

Table 2. Summary metrics and multimetric indices for benthic macroinvertebrate communities sampled from Upper Delaware Scenic and Recreational River, October 2008. Direction of metric or index response to increasing stream ecosystem integrity are denoted parenthetically by + or -. Richness metrics included total taxa richness (Total), and richness of Ephemeroptera (E), Plecoptera (P), Trichoptera (T), and Collector or Filter feeders (C-F). Proportional metrics included the percent of individuals in samples that were non-insect taxa (%Non-insects) or that comprised the combined five dominant taxa in the community (%5 dominant). Indices were the Macroinvertebrate Tolerance Index (MTI) and the Macroinvertebrate Biotic Integrity Index (MBII).

	Richness (+)					**Proportional (-)**		**Shannon (+)**		**Indices**	
Stream	**Total**	**E**	**P**	**T**	**C-F**	**%Non-insects**	**%5 dominant**	**Diversity**	**Evenness**	**MTI (-)**	**MBII (+)**
Equinunk Creek	35	8	6	9	6	1	57	1.20	0.78	3.8	65.8
Ten Mile River	34	6	4	14	6	2	61	1.20	0.78	3.8	64.5
Callicoon Creek	32	9	4	10	7	0	61	1.12	0.75	3.6	62.8
Masthope Creek	31	8	3	12	6	2	59	1.21	0.81	3.6	61.9
Hankins Creek	30	9	7	7	5	0	71	1.06	0.72	3.3	61.9
Mongaup River	38	7	3	18	6	8	63	1.03	0.65	3.6	61.0
Little Equinunk Creek	32	7	5	9	7	1	69	1.09	0.73	3.4	58.4
Calkins Creek	30	8	3	9	5	2	59	1.13	0.77	3.6	57.1
E. Branch Delaware	24	7	2	9	5	1	76	0.91	0.66	3.7	54.1
Shohola Creek	33	5	3	13	6	3	74	0.94	0.62	3.8	53.8
Lackawaxen River	35	6	5	11	5	9	67	1.11	0.72	4.2	50.8
W. Branch Delaware	23	7	2	6	5	4	68	1.07	0.79	4.1	46.9

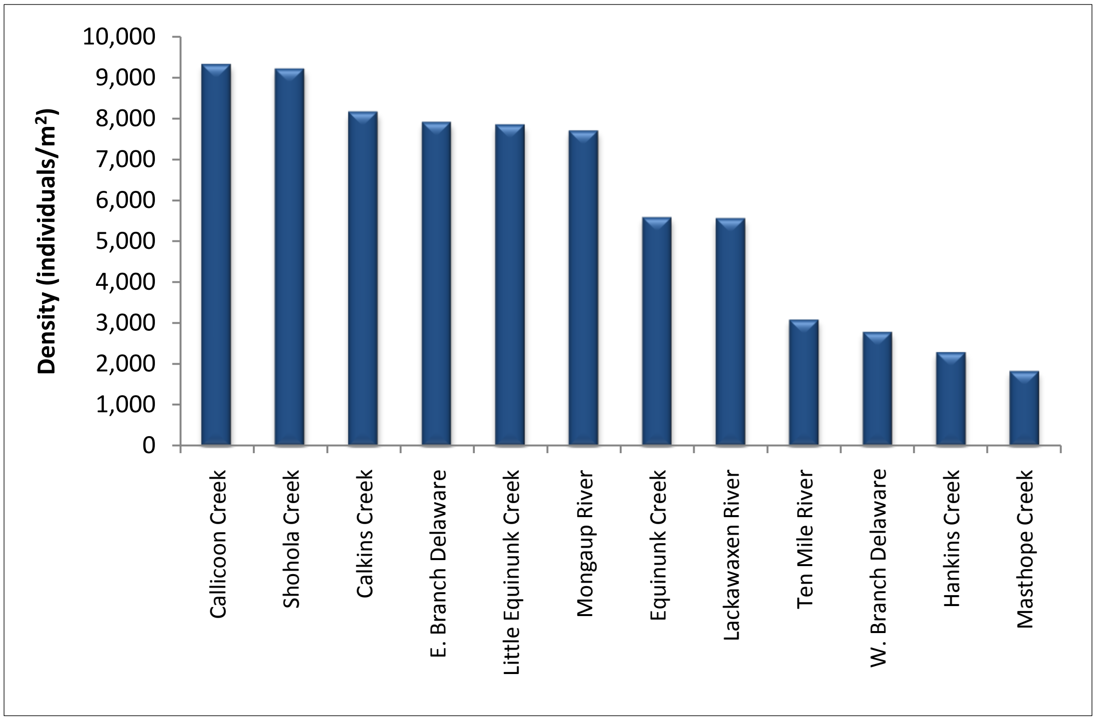

Figure 3. Density (individuals/m^2) of benthic macroinvertebrates collected at sampling sites throughout the Upper Delaware Scenic and Recreational River in October 2008.

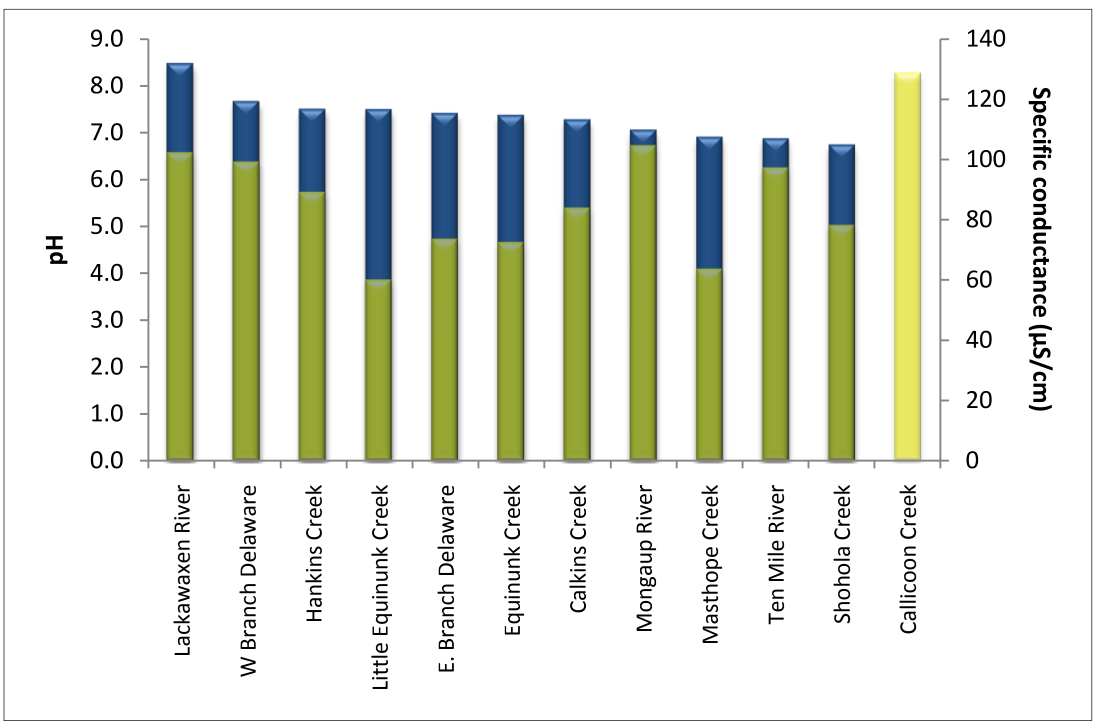

Figure 4. pH (blue bars) and specific conductance (yellow bars) of water at sampling sites throughout the Upper Delaware Scenic and Recreational River in October 2008. pH data were not collected at Callicoon Creek due to equipment difficulties.

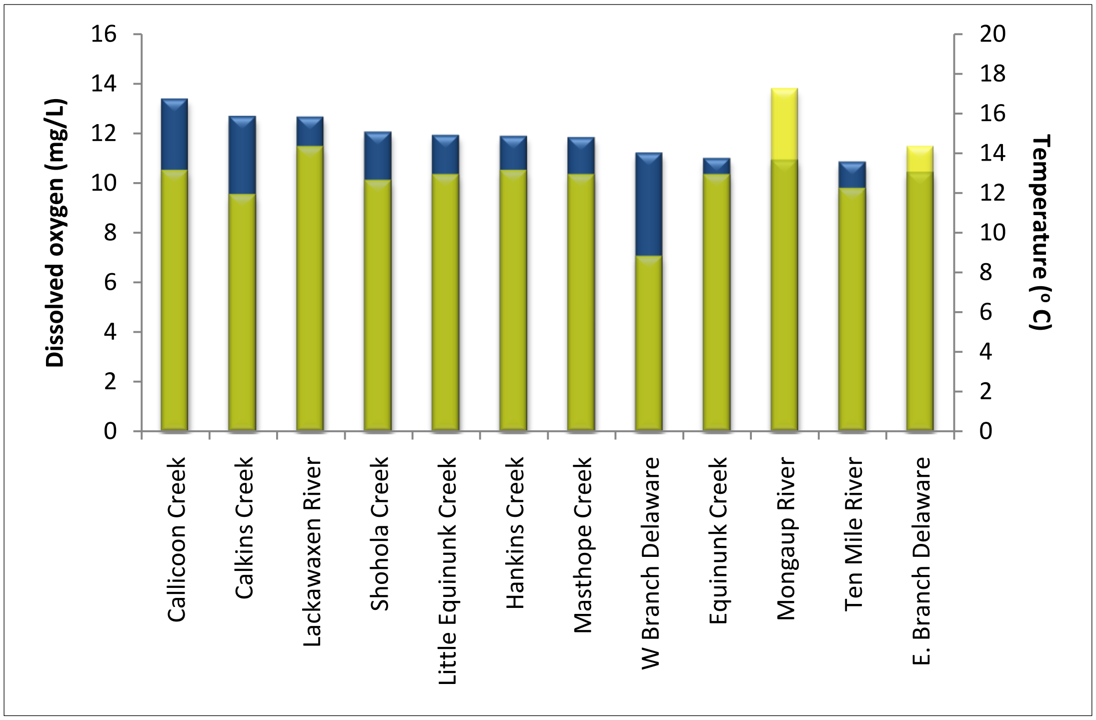

Figure 5. Dissolved oxygen concentration (blue bars) and temperature (yellow bars) of water at sampling sites throughout the Upper Delaware Scenic and Recreational River (UPDE) in October 2008.

Discussion

This report summarized results from the first sampling season of the ERMN BMI monitoring program at UPDE. The effort was largely successful in that it provided quality data for all of the selected sites. All components of the protocol worked well, which was not a surprise because they were based largely on widely used USGS protocols. The primary challenge to interpreting the data (as discussed in the methods section) was that, because the ERMN protocol did not precisely follow all other state or regional protocols, comparing our data with other efforts included qualifications.

Given that this report represented the first year of data collection, there were few inferences or management recommendations that could be confidently made. Biological communities (including BMI) can vary through time due to a range of naturally occurring biotic phenomena (e.g., interspecific competition, predation) and abiotic disturbances (severe drought, floods). It will take several years to determine the degree to which BMI communities naturally vary throughout UPDE and the rest of the ERMN. Once natural variability of BMI communities is quantified, we will be in a better position to make inferences about the relative condition of sampled streams.

With each future sampling season, the ERMN BMI monitoring program will be refined and improved. It is anticipated that metrics and indices will be calibrated so that more precise and accurate comparisons can be made between UPDE streams and streams throughout the region. In the future, metrics and indices will be catered to UPDE stream “types,” which the ERMN will use in combination with spatial data to make better assessments regarding stream ecosystem condition at a park scale. In addition to calibrating the MBII and its constituent metrics, the ERMN will add other measures of stream integrity as more data are gathered. For example, another meaningful way to express BMI community condition is with Observed/Expected Indices that estimate the number of taxa (e.g., genera) that have been lost (i.e., extirpated) from a given stream (Yuan 2008). To use these methods, the expected number of taxa for a given stream type must be established from the least disturbed streams in the region (i.e., UPDE). This process will likely begin after next season when assessments regarding natural variability of BMI communities can be at least coarsely made.

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